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Modeling of Mine Countermeasure Dart Dispense

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Abstract

Mine countermeasure systems are currently under development to defeat beach- and surf-zone mines by dispensing small darts from a larger primary projectile body (Hydra-7, MODS, and CMCO). These programs currently lack modeling and simulation techniques that incorporate all of the complexities of the aerodynamics of the dart dispense. OVERFLOW software will be used to perform computational fluid dynamics (CFD) simulations, using overset structured grids (created with OVERGRID), of representative delivery vehicles dispensing numerous (up to 381) mine countermeasure darts. These darts, approximately 5 to 6 inches in length, are designed to disable mines in the beach and surf zones after being dispensed in a uniform pattern over a given area. OVERFLOW will solve the equations of motion for each moving dart body and thus provide a time-accurate prediction of the dispense event. The results of 8 OVERFLOW dart dispense simulations of Venom Penetrator darts, each with a different Mach number, spin rate, and number of darts, will be presented and discussed.

1. Introduction

The Navy and Marine Corps need the capability to rapidly clear mines in the surf-zone and beach-zone regions to permit rapid, effective transition from the sea to land. Systems developed to date have proven effective but require extensive Marine Corps manpower to deploy and initiate. More recent 6.3 initiatives have concentrated on developing aircraft or projectile-launched systems that would dispense large numbers of mine-neutralizing darts or penetrators without requiring manpower to be in or very near the minefields.

To support the development and evaluation of dart dispense concepts, we have developed a set of computational tools to accurately predict the dispersion pattern, velocities, and orientations of the darts (Figure 1) when they are released from any of the various dispense concepts. Tests such as sled tests with witness panels can provide good data on dart location and some insight into dart orientation at a specific distance from the dispense event. While simulations will not replace all testing, modeling & simulation has the advantage of providing dart location and orientation at any distance from the dispense event and can provide dart angular rate information that may be impossible to deduce from such tests.

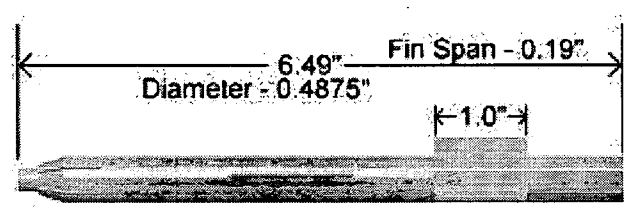

Figure 1. Mine Countermeasure Dart

A Dart Dispense Modeling & Simulation Working Group was formed as a result of a need identified during an Initial Dispensing Technology Workshop, coordinated by Mr. Brian Almquist, Office of Naval Research, which was held in February 2002. They held their first kickoff meeting in June 2002. Members of the initial team included: Office of Naval Research, Naval Surface Warfare Center/Indian Head, Naval Surface Warfare Center/Panama City, Army Aeroflightdynamics Directorate Ames Research Center, NASA/Langley, NEAR Inc., and Digital Fusion Inc. In FY 2003, a high performance computing (HPC) project titled "Modeling

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of Mine Countermeasure Dart Dispense" was initiated. The project was approved as a Challenge Project in FY 2007.

2. Objective

Full Navier-Stokes simulations of dispensing penetrators will be performed using OVERFLOW, a CFD computer code developed by a team of Army and National Aeronautics and Space Administration scientists directed by Dr. Robert L. Meakin under the Department of Defense (DoD) High Performance Computing Modernization Program (HPCMP) initiative known as "Common High Performance Computing Software Support Initiative." The flow solver, OVERFLOW, is a general Navier-Stokes solver for problems involving complex geometry. The code contains a comprehensive grid generation package and support utilities. The software is appropriate for steady or unsteady, viscous or inviscid flow, with static or moving bodies. It can accommodate an arbitrary number of bodies that may involve relative (rigid-body) motion. Body motion can be prescribed, or driven by aerodynamic and applied loads. An additional module was added to the code by Dr. Meakin and Pieter Buning in FY 2003 and tested in FY 2005 that allows for collisions between bodies and a corresponding elastic response.

The challenge of this project is to determine how many dispensing darts can be simulated simultaneously, such that an accurate prediction of the resulting dispense pattern can be generated. In the case of the Mine Obstacle Defeat System (MODS) mine countermeasure weapon being developed by Boeing, the dispense event will include over 4,000 darts being dispense at one time. In order to capture the flight and dispense dynamics of this event, it is necessary to simulate as much of the dart pack as possible, and to determine how many axial layers and radial rows of darts must be modeled to capture all the relevant flight dynamics. Therefore, the objectives of the subject Challenge Project are to use the available HPC resources to simulate as many darts as possible and to determine the sensitivity of the resulting impact pattern to initial dispense parameters, such as spin rate, Mach number, and number of darts.

3. Methodology

To accomplish the goal of modeling as many dispensing darts as possible and thus producing a high fidelity prediction of the resulting dart pattern, a successive approach was taken in which the number of darts simulated was systematically increased. First *individual* darts were modeled using several Computational Fluid Dynamics packages, including OVERFLOW. CFD results were compared to aerodynamic coefficients measured during aeroballistics testing, and it was determined that OVERFLOW would be the CFD model of choice for dart dispense simulations.

Next, extensive OVERFLOW CFD simulations of unsteady dart motions were conducted in FY 2006. *Single darts* with initial angles-of-attack and spin conditions were simulated to determine predicted pitch and yaw damping characteristics. A series of dart-to-dart runs using *three darts* in varying axial and radial positions was accomplished to characterize dart-to-dart drafting effect. Following that, simulations of *19-dart clusters* were conducted to determine more detailed dart-to-dart interference effects. An OVERFLOW simulation of a spin-released, moving-body cluster of 19 darts was conducted and analyzed. This simulation showed a strong expulsive radial force on the outside ring of darts, when the darts were closely packed together. This force may play a significant role in the overall dispense pattern of multiple darts. A similar OVERFLOW simulation was conducted by Digital Fusion, in which the center 7 darts of the pack were replaced by a hemispherical-nosed rigid body.

A full three-dimensional OVERFLOW simulation of the dispensing of the inner *54 darts* of a single Naval Gun Fire Support canister was conducted. This simulation, which calculates the flow field conditions around the 5" dispense round as well as the aerodynamic forces and motions of 54 individual darts, was run along with the collisions module developed for OVERFLOW. This simulation was directly compared to dart dispense data from gun launched tests conducted at NSWC Dahlgren.

After successfully modeling 19 dart clusters (configured as one axial layer), simulations of multiple axial layers were performed. Therefore, simulations of dispensing darts with *38 darts* (two axial layers) and *57 darts* (three axial layers) were conducted. Finally, in preparation for the Challenge Project, a simulation with *111 darts* (3 axial layers and 3 radial rows) was run in OVERFLOW. For each of the preliminary dispense simulations, the following initial conditions were used: Mach number = 1.2 and Dispense Spin Rate = 9 Hz.

Next, a Challenge Project matrix was created which included dispense simulations with multiple darts in a MODS type dispense. Each of the eight simulations was allotted approximately 100,000 HPC CPU hours from the total Challenge Project allocation. Based on benchmark work and experience with the previous multiple dart simulations, a maximum number of dart layers and rows were determined for the Challenge Project simulations. The matrix, Table 1, which investigates the sensitivity of dispense to Mach number, spin rate, and dart cluster size, is as follows:

Table 1. Challenge Project Simulation Matrix

Run Number	#Axial Layers	# Radial Rows	Total # of Darts	Spin Rate	Mach Number
1	3	5	273	6	1.2
2	3	5	273	12	1.2
3	3	5	273	18	1.2
4	3	3	111	12	1.2
5	3	4	183	12	1.2
6	3	6	381	12	1.2
7	3	5	273	12	1.6
8	3	5	273	12	2.0

4. Results

OVERFLOW simulations of dispensing dart clusters have been successfully run for packs containing up to 111 darts to date. These simulations represented three axial dart layers and three radial rows of darts, and were run at Mach 1.2. High fidelity visualization software was used to study the simulation results and to generate animations of the predicted dart dispense behavior. In general, the animations showed a high degree of chaotic dart motion due to dart-to-dart collisions. High dart angles-of-attack were witnessed especially in the rearward dart packs. Furthermore, it was observed that darts in the outer radial rows were expelled radially at higher velocities than inner row darts. This result is somewhat validated by dart impact patterns observed during actual dart dispense flight testing, in which pattern sizes were in general larger than predicted by normal kinematic spin dispense calculations. Several snapshots in time of the 111 dart pack dispense prediction are shown in Figure 2.

Efforts are currently underway to execute the Challenge Project matrix of dispense simulations. A model containing 273 darts has been successfully meshed; however, the completed simulation results were not available at the time of this report. Several lessons have been learned already during model preparation. First, it was observed that system memory is a greater obstacle than run times. Also, it appears the meshed model sizes, as well as output file sizes, may be limiting factors, because of difficulties with file storage and transfer. Finally, the investigators will also face challenges related to visualization of model results.

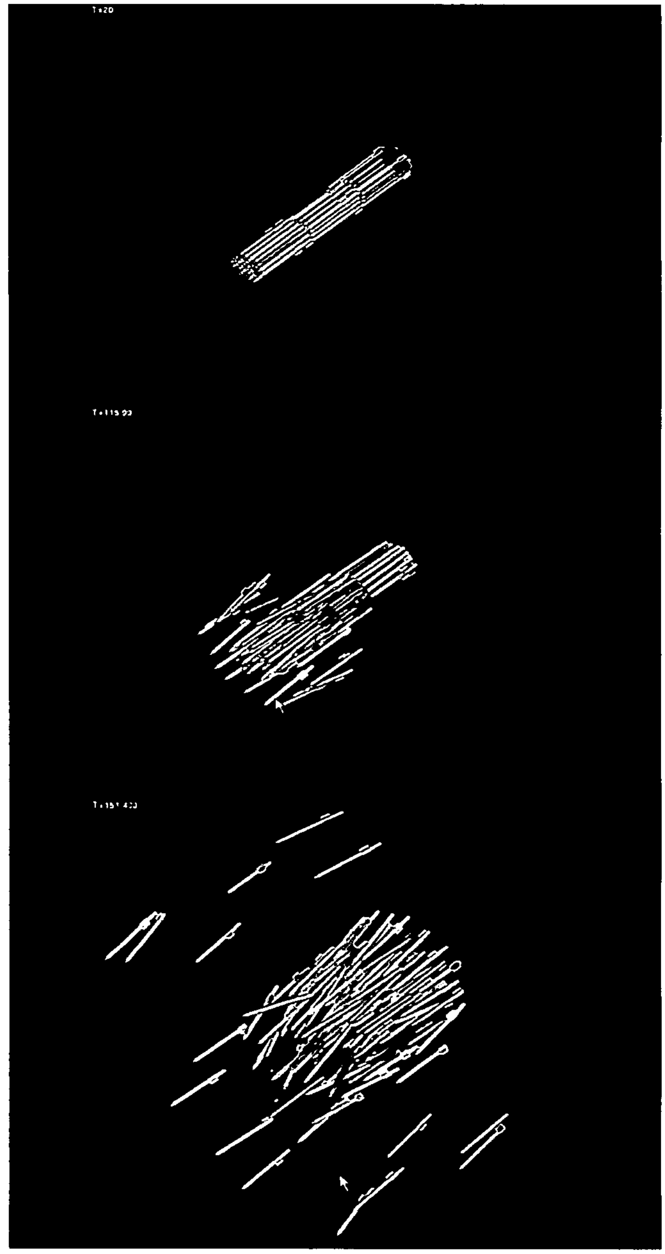

Figure 2. 111 Dart Dispense Simulation